(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 983 757 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
08.03.2000 Bulletin 2000/10

(51) Int. Cl.[7]: **A61F 9/01**

(21) Application number: **99117382.4**

(22) Date of filing: **03.09.1999**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **04.09.1998 JP 25152098**
03.06.1999 JP 15610299

(71) Applicant: **Nidek Co., Ltd.**
Gamagori-shi, Aichi 443-0035 (JP)

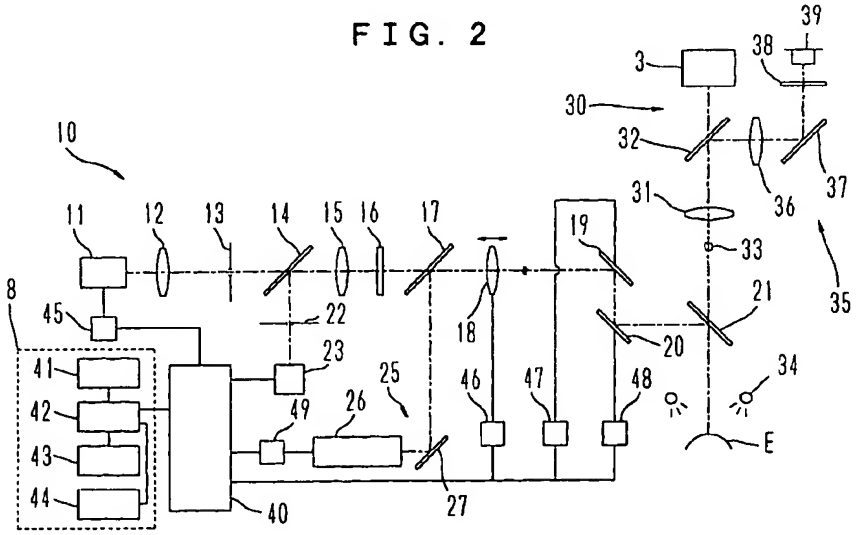
(72) Inventor: **Sumiya, Toshifumi**
Kota-cho, Nukata-gun, Aichi 444-0116 (JP)

(74) Representative:
Blumbach, Kramer & Partner GbR
Radeckestrasse 43
81245 München (DE)

(54) Corneal surgery apparatus

(57) In a corneal surgery apparatus (10), a corneal shape measurement unit for measuring a three-dimensional shape of a cornea (E) includes a measurement light projecting optical system (11) for projecting measurement light onto the cornea (E) and its convergent point is shifted by moving a focusing lens (18) along an optical axis, a measurement light receiving optical system including a photo-detector (23) for receiving reflected light from the cornea (E) and its convergent point is shifted by moving a focusing lens (18) along an optical axis, a scanning unit (19, 20) for shifting a projection spot of the measurement light on the cornea (E) in XY directions and an arithmetic unit (8) for performing arithmetic to obtain the three dimensional shape of the cornea (E) from a position of the projection spot, a result detected by the photo-detector (23) and a position to which the focusing lens is moved.

FIG. 2



EP 0 983 757 A2

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a corneal surgery apparatus for ablating a part of a cornea of a patient's eye to correct a refractive error of the eye or to remove a lesion therefrom.

2. Description of Related Art

[0002] Conventionally known is a corneal surgery apparatus that ablates a corneal stroma of a patient's eye with an excimer laser or the like to change a refractive power of the eye to correct ametropia including myopia, hypermetropia, astigmatism and the like, or to remove an affected part of the cornea such as opacity. Also known is a corneal shape measurement apparatus (hereinafter referred to as a topography apparatus) that projects a placido ring onto a cornea and photographs an image of the placido ring to measure the corneal surface shape. Further, it has also been suggested to input the corneal shape data obtained by the topography apparatus to a corneal surgery apparatus. An amount to be ablated is calculated from the data and also the post-operative refractive power to be obtained. The ablation is carried out in accordance with the calculated ablation amount.

[0003] However, the above-described way presents the following problems. One of the problems lies in the case of measuring a corneal shape of a patient's eye by a topography apparatus first, and then performing surgery to correct the refractive power by a separate corneal surgery apparatus based on the data captured from the topography apparatus. In this case, the positional relationship between the topography apparatus and the patient's eye is not necessarily the same as the positional relationship between the corneal surgery apparatus and the patient's eye. It is especially so, when the measurement by the topography apparatus is carried out with the patient being sit and fixed by the face, while the surgery by the corneal surgery apparatus is carried out with the patient being laid on his back. Due to the inclination of the face, the gravity and other various factors, it is often the case that the patient's eye is not in a uniform state. This results in the possibility of ablating an unintended part of the cornea. In this case, the post-operative corneal shape may differ from the expected one and the refractive error may not be corrected as expected.

[0004] One possible way to address the above problem is to combine the corneal surgery apparatus and the topography apparatus into one apparatus so as to make the topography position and the corneal surgery position coincide with each other relative to the patient's eye. However, an attempt to make one apparatus by combining the topography apparatus including a placido ring projecting unit and a TV camera for photographing its corneal reflex and the like with the corneal surgery apparatus including a laser irradiation optical system and an observation optical system will results in an undesirably large apparatus.

SUMMARY OF THE INVENTION

[0005] The present invention has been made in view of the above circumstances and has an object to overcome the above problems and to provide an apparatus for corneal surgery which is small and compact, while being capable of preventing displacement between a corneal shape measurement position and a laser beam irradiation position upon corneal surgery to remove a part of the cornea with a laser.

[0006] Additional objects and advantages of the invention will be set forth in part in the description which follows and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

[0007] To achieve the objects and in accordance with the purpose of the present invention, as embodied and broadly described herein, a corneal surgery apparatus which ablates corneal tissue with a laser beam, the apparatus comprises an irradiation unit including a light directing optical system for directing the laser beam to an intended range on a cornea of a patient's eye, wherein the laser beam has a wavelength in a far ultraviolet region and intensity capable of causing ablation and a corneal shape measurement unit, provided inside the apparatus, for measuring a three-dimensional shape of the cornea, the corneal shape measurement unit including a measurement light projecting optical system for projecting measurement light onto the cornea and its convergent point is shifted by moving a focusing lens along an optical axis, a measurement light receiving optical system including a photo-detector for receiving reflected light from the cornea and its convergent point is shifted by moving a focusing lens along an optical axis, a scanning unit for shifting a projection spot of the measurement light on the cornea in XY directions and an arithmetic unit for performing arithmetic to obtain the three-dimensional shape of the cornea from a position of the projection spot, a result detected by the photo-detector and a position to which the focusing lens is moved.

[0008] As described above according to the present invention, it is possible to prevent the displacement between the corneal shape measurement position and the laser irradiation spot upon corneal laser surgery to remove a portion of the cornea. Simultaneously, it is also possible to make the whole apparatus compact in size. In addition, according to the present invention, the corneal thickness can be measured so that judgement

on ablation or adjustment of the ablation amount may be made based on the measured corneal thickness.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present invention and, together with the description, serve to explain the objects, advantages and principles of the invention. In the drawings,

Fig. 1 is a view showing an overall configuration of a corneal surgery apparatus of the present invention;
Fig. 2 is a view showing a schematic configuration of an optical system and a control system provided in the corneal surgery apparatus of the present invention;
Fig. 3 is a view showing an image of an anterior part of the patient's eye that a CCD camera receives;
Fig. 4 is a view showing light distribution along a line A-A';
Fig. 5 is a view explaining a scan of the measurement light over the cornea in two-dimensional directions;
Figs. 6A and 6B are views explaining difference in light quantity due to the deviation of the measurement light on the cornea in the direction of the thickness; and
Fig. 7 is an example displaying measured corneal shape data and an obtained ablation amount.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] A detailed description of one preferred embodiment of a corneal surgery apparatus embodying the present invention will now be given referring to the accompanying drawings.

[Overall Configuration]

[0011] Fig. 1 is a view showing an overall configuration of a corneal surgery apparatus of the present invention. The reference numeral 1 is a main body of the surgery apparatus and optical systems and a control system are partially embedded therein. 2 is an arm portion for directing a laser beam to a patient's eye. An end portion 2a of the arm portion 2 is provided with a binocular microscope unit 3 for observing the patient's eye, an illumination unit 4 and the like. The end portion 2a may be moved in X, Y and Z directions by a driving device. For the details of this arm portion 2 (the end portion 2a) and its driving devise, see Japanese Published Unexamined Patent Application HEI 9-149914 that corresponds to US Patent Application 08/979,846 and also to EP Published Unexamined Patent Application 0765648 by the present applicant.

[0012] 5 is a controller provided with a joystick 6 for signaling to move the arm portion 2 (the end portion 2a) in X and Y directions and also with various operation switches. 7 is a foot switch for signaling to irradiate a laser beam. 8 is a computer to perform input of various data about surgical conditions as well as to perform arithmetic, storage and display of corneal shape data, ablation data and the like. 9 is a bed on which the patient lies down.

[Configuration of each system]

[0013] Fig. 2 is a view showing a schematic configuration of the optical systems and the control system of the corneal surgery apparatus of the present invention. Concerning the optical systems, descriptions are given separately to a corneal shape measurement optical system, a laser irradiation optical system, an observation optical system and an eyeball position detecting optical system.

(A) Corneal shape measurement optical system

[0014] 10 is the corneal shape measurement optical system for measuring a three-dimensional corneal shape. 11 is a laser beam source for emitting a laser beam which functions as measurement light to measure the corneal shape. In this embodiment, an infrared semiconductor laser beam source that emits infrared laser at a wavelength of 800 nm is used. The measurement light does not necessarily have to be infrared light, yet it is advantageous in that infrared light is not glaring and therefore the discomfort of the patient upon a measurement is reduced. 12 is a focusing lens, 13 is a pinhole (aperture) and 14 is a polarizing beamsplitter. 15 is a collimating lens that makes the infrared laser beam a parallel beam and 16 is a quarter waveplate.

[0015] 17 is a dichroic mirror by which an optical axis of a laser irradiation optical system 25 described later is made coaxial with an optical axis of the measurement optical system 10. The dichroic mirror 17 transmits the infrared laser beam that the laser beam source 11 emits but reflects an excimer laser beam that an excimer laser head 26, mentioned later, emits. 18 is a focusing lens for focusing the infrared laser beam and the excimer laser beam. The lens 18 is arranged movably back and forth along the optical axis. 19 and 20 are scanning mirrors which scan the infrared laser beam and the excimer laser beam over the cornea in two-dimensional directions. In this embodiment, a galvano-mirror is used as the scanning mirrors 19 and 20 respectively.

[0016] 21 is a dichroic mirror by which the common optical axis of the measurement optical system 10 and the laser irradiating optical system 25 is made coaxial with a common optical axis of an observation optical system 30 and an eyeball position detecting optical sys-

tem 35 described later. The dichroic mirror 21 reflects the infrared laser beam having a wavelength of 800 nm emitted from the laser beam source 11 as well as the excimer laser beam having a wavelength of 193 nm, but transmits visible light having a wavelength in a range of about 400-700 nm as well as the infrared laser beam having a wavelength of 950 nm emitted from infrared illumination light sources 34 described later. The reference letter E denotes a/the cornea of the patient's eye. The scanning mirrors 19 and 20, and also the dichroic mirror 21 are provided inside the end portion 2a.

[0017] 22 is a pinhole (aperture), 23 is a photo-detector that detects the infrared laser beam being measurement light reflected from the cornea E. The pinhole 13 and the pinhole 22 are arranged to be conjugate with each other relative to the cornea E. It should be noted that the lens 18 also serves the function of making the reflected light from the cornea E parallel light and the lens 15 also serves the function of focusing/converging the reflected light.

(B) Laser Irradiating Optical System

[0018] 25 is the laser irradiation optical system for irradiating a laser beam to ablate a cornea. A laser head 26 irradiates a laser beam, which has no thermal effect on a corneal tissue, for ablation upon corneal surgery. Used in this embodiment is an ArF excimer laser head that emits an ArF excimer laser beam having a wavelength of 193 nm. This therapeutic laser beam has to be a laser beam having its wavelength in a far ultraviolet region to ablate corneal tissue. It is desirable to use a laser beam having a wavelength of 150-230 nm, and more preferably, an ArF laser beam having a wavelength of 193 nm. 27 is a mirror that reflects the excimer laser beam emitted from the laser head 26. The excimer laser beam emitted from the laser head 26 is reflected and deflected first by the mirror 27 and then by the dichroic mirror 17. Thereafter, the excimer laser beam passes through the lens 18 and is sequentially reflected and deflected by the scanning mirrors 19 and 20, and finally by the dichroic mirror 21, thereby being directed onto the cornea E.

(C) Observation Optical System

[0019] 30 is the observation optical system for observing the patient's eye. 31 is an objective lens. 32 is a dichroic mirror that transmits visible light, but reflects the infrared light having a wavelength of 950 nm emitted by the infrared illumination light sources 34. Visible illumination light from the illumination unit 4 illuminates an anterior part of the patient's eye and forms an image thereof. Luminous flux of the image passes through the dichroic mirror 21, the lens 31 and the dichroic mirror 32, and then enters the microscope unit 3. Consequently, a surgeon can observe the patient's eye with the binocular microscope unit 3. In addition, the observation optical system 30 includes a not illustrated reticle plate inserted therein. This allows to provide a reference for alignment of the patient's eye in X and Y directions.

[0020] Also included in the observation optical system 30 is a target projecting optical system comprising two slits (reference may be made to Japanese Published Unexamined Patent Application HEI 6-47001 that corresponds to USP 5,562,656 by the present applicant). The observation optical system 30 is arranged inside the end portion 2a. 33 is a fixation light arranged on the optical axis of the observation optical system 30 and emits visible light.

(D) Eyeball Position Detecting Optical System

[0021] 35 is the eyeball position detecting optical system for detecting the eyeball position of the patient's eye. 34 are the infrared illumination light sources which emit infrared light at a wavelength of 950 nm and a total of four illumination light sources 34 are arranged at 90 ° intervals about the optical axis. 36 is a photographing lens and 37 is a mirror. 38 is an infrared light transmitting filter to cut off noise light. 39 is a CCD camera. The eyeball position detecting optical system 35 is also arranged inside the end portion 2a.

[0022] The luminous flux of the image of the anterior part of the patient's eye illuminated by the illumination light sources 34 passes through the dichroic mirror 21 and the lens 31, and then is reflected by the dichroic mirror 32. Thereafter, the luminous flux passes through the photographing lens 36 thereby forming an image on a photographing surface of the camera 39 via the mirror 37 and the filter 38. Upon the passage of the luminous flux, the filter 38 cuts off the visual light reflected slightly by the dichroic mirror 32.

[0023] The camera 39 detects the eyeball position in the following way. Fig. 3 is a view showing the image of the anterior part of the eye captured by the camera 39 and Fig. 4 is a view showing distribution of the light along the line A-A' (shown in Fig.3) obtained from photographing signals of the camera 39. As shown in Fig. 4, the light distribution differs depending on its corresponding part of the eye such as a pupil, an iris and a sclera. Accordingly, from information about the light distribution, coordinates of each pupil edge along its lateral direction are detect. Further, from the coordinates of the pupil edge detected thereby, coordinates of its center in the lateral direction are as well obtained. Similarly, coordinates of a center of the pupil in its vertical direction are obtained from information about the light distribution along the vertical line B-B' (shown in Fig.3). That is to say, the light distribution along the two lines allows to locate the pupil center with respect to the optical axis of the detecting optical system 35 (equally meaning the optical axes of the measurement optical system 10 and the irradiating optical system 25) being adjusted to have a predetermined positional relationship on the photographing element of the camera 39.

(E) Control System

[0024] 40 is a control system embedded within the main body 1. The control system 40 drives and controls the laser beam source 11, the lens 18, the scanning mirrors 19 and 20, the laser head 26, the fixation light 33, the illumination light sources 34 and the like. 41, 42, 43, 44 are respectively an input unit (a key board, a mouse and the like), a arithmetic analytical processing unit (CPU and the like), a display unit (a monitor), and an output unit (a printer, a floppy disk drive and the like) all of which are provided to the computer 8. The input unit 41 is used to input laser irradiation conditions such as an intended post-operative refractive power, a corneal radius and the like. The processing unit 42 processes signals from the photo-detector 23 thereby obtaining corneal shape data. The processing unit 42 also processes the corneal shape data and the inputted irradiation conditions thereby obtaining ablation data such as an amount of the cornea to be ablated and the like. The data processed by the processing unit 42 is sent to the control unit 40. Base on the processed data, the control unit 40 drives and controls the scanning mirrors 19 and 20, the laser head 26 and the like. The display unit 43 displays both the pre-operative corneal shape and post-operative corneal shape along with other information in accordance with the corneal shape data sent from the processing unit 42. The output unit 44 outputs various obtained data.

[0025] 45 is a driving circuit for the laser beam source 11, 46 is a driving circuit for the lens 18, 47 and 48 are driving circuits for the scanning mirrors 19 and 20 respectively, and 49 is a driving circuit for the laser head 26 (driving circuits for the fixation light 33 and the illumination light sources 34 are not illustrated). A driving circuit for the arm portion 2 is also controlled by the control unit 40.

[0026] Hereinafter, descriptions are given to operations of the apparatus with the above described configuration. The descriptions focus on surgery for correcting a refractive error.

[0027] The surgeon first makes the patient lie on the bed 9 and places the arm portion 2 (the end portion 2a) above the patient's eye. Thereafter, the surgeon lights the illumination unit 4, the fixation light 33, the illumination light sources 34 and the like and then makes the patient's eye fixate at the fixation light 33. While observing the anterior part of the patient's eye being illuminated by the illumination unit 4 with the microscope unit 3, the surgeon operates the joystick 6 to make alignment in X and Y directions so as to bring a not illustrated reticle and the pupil into a predetermined positional relationship with each other. In addition, the surgeon operates a focus adjusting switch 60 to perform alignment in a Z direction. When signals generated in response to the operations of the joystick 6 (and the switch 60) are inputted to the control unit 40, the control unit 40 actuates the driving circuit for the arm portion 2 so as to move the arm portion 2 (the end portion 2a) in X and Y directions (and also in a Z direction).

[0028] During the alignment, if an auto-alignment changeover switch 61 provided on the controller 5 is turned on, an auto-alignment starts. When the patient's eye is in a range where the pupil center is detectable by the detecting optical system 35, the control unit 40 moves the arm portion 2 (the end portion 2a) in X and Y directions so as to bring the optical axes of the measurement optical system 10 and the irradiating optical system 25 into coincidence with the pupil center.

[0029] To perform the corneal shape measurement or irradiation of the laser, while keeping the optical axes of the measurement optical system 10 and the irradiating optical system 25 into coincidence with the pupil center, the surgeon depresses a ready switch 62 provided on the controller 5 after turning on the auto-alignment changeover switch 61 and completing the alignment. When the ready switch 62 is depressed, a predetermined position on the photographing element is stored as a reference position and an eyeball tracking mechanism (auto-tracking) is actuated thereby moving the arm portion 2 (the end portion 2a) so as to bring the reference position into coincidence with the pupil center. For the details of the auto-alignment and the auto-tracking, see Japanese Published Unexamined Patent Application HEI 9-149914 that corresponds to US Patent Application 08/979,846 and also to EP Published Unexamined Patent Application 0765648 by the present applicant.

[0030] When the alignment of the patient's eye is completed, a three-dimensional shape of the cornea E is measured by the measurement optical system 10. The infrared laser beam of the linearly polarized light emitted from the laser beam source 11 converges via the lens 12 on the pinhole 13. After converging and passing through the pinhole 13, the infrared laser beam passes though the beam splitter 14, because the laser beam source is arranged to adapt its polarization direction, and then is made parallel light by the lens 15. Thereafter, the linearly polarized light is converted into circularly polarized light by the quater waveplate 16, which is arranged to form an angle of 45 ° between its retarder principal plane and the polarization plane of the infrared laser beam. Next, the infrared laser beam passes through the dichroic mirror 17 and converges via the lens 18. Finally, the infrared laser beam is successively reflected and deflected by the scanning mirrors 19 and 20 to converge in the vicinity of the cornea E. Through controlling the reflection angles (deflection angles) of the scanning mirrors 19 and 20, the infrared laser beam comes to scan in two-dimensional directions.

[0031] Here, descriptions are given to the scan of the infrared laser beam by the scanning mirrors 19 and 20 over the cornea E in two-dimensional directions. Fig. 5 is a view explaining the scan with the measurement light over the cornea in two-dimensional directions. The control unit 40 drives the scanning mirrors 19 and 20 via the

respective driving circuits 47 and 48 thereby scanning the infrared laser beam 51 being the measurement light over a scanning range starting from the top left to the bottom right in succession of $(X_1, Y_1) \cdots (X_n, Y_1)$, $(X_1, Y_2) \cdots (X_n, Y_2) \sim (X_1, Y_n) \cdots (X_n, Y_n)$.

[0032] While diverging, the infrared laser beam reflected by the cornea E is reflected and deflected successively by the scanning mirrors 20 and 19 and then made to be parallel beam again by the lens 18. Thereafter, the infrared laser beam passes through the dichroic mirror 17 and is converted from circularly polarized light into linearly polarized light by the quater waveplate 16. After being converged by the lens 15, the infrared laser beam of the linearly polarized light is reflected by the polarizing beamsplitter 14 because its polarization direction is rotated 90° from the polarization direction at the time the infrared laser beam runs toward the cornea E. The infrared laser beam converges on, and passes through, the pinhole 22 and enters into the photo-detector 23.

[0033] When the corneal surface (anterior surface or posterior surface) is on the two-dimensional flat surface (or may be curved surface) over which the convergent point of the infrared laser beam scans, as shown in Fig. 6A, the infrared laser beam reflected therefrom goes back through the same optical path as described above and converges on the pinhole 22. As the result, relatively large quantity of light enters into the photo-detector 23. On the contrary, when the corneal surface (anterior surface or posterior surface) is not on the two-dimensional flat surface (or may be curved surface) over which the convergent point of the infrared laser beam scans, in other words when the infrared laser beam is reflected off the convergent point, as shown in Fig. 6B, the reflected infrared laser beam does not converge on the pinhole 22 and become blurred. As the result, almost no light enters into the photo-detector 23. Accordingly, when scanning the convergent point of the infrared laser beam over the two-dimensional flat surface, the reflected light is sufficiently detected by the photo-detector 23 only where the corneal surface is within the surface. This allows to obtain a contour of the cornea E on the surface. The pinholes 13 and 22 are arranged to be conjugate with each other relative to the cornea E, and thereby forming a confocal optical system (that is to say a point light source and a point detector are in image forming relation with each other relative to one point of an object).

[0034] Further, the control unit 40 moves the lens 18 via the driving circuit 46 along the optical axis so that the two-dimensional flat surface over which the convergent point of the infrared laser beam scans is gradually shifted in the direction of the thickness of the cornea. The contour of the cornea E on the surface is measured repeatedly in the same way mentioned above but gradually shifted in the direction of the thickness. By combining the obtained contours of the cornea E on the surface into a three-dimensional shape, three-dimensional shapes of the anterior and the posterior cornea E are obtained.

[0035] Detection signals from the photo-detector 23 are fed into the processing unit 42 via the control unit 40 and the processing unit 42 obtains three-dimensional corneal shape data based on the detection signals and irradiation spots by the infrared laser beam in three-dimensional directions (the irradiation spots are calculated from the deflection angles of the scanning mirrors and the position of the lense 18). In addition, the corneal thickness is obtained based on the anterior and posterior shapes of the cornea E. In accordance with the corneal shape data and the corneal thickness data obtained thereby, a map 70, a sectional view 71 and other numeral data (see Fig. 7) are displayed on the display unit 43.

[0036] After completing the corneal shape measurement by the measurement optical system 10, the surgeon inputs intended post-operative corneal data such as refractive power, corneal radius and the like with the use of the input unit 41 (the data may be inputted in advance). The processing unit 42 determines ablation data such as necessary amount to be ablated and the like to correct refractive error based on the corneal shape data obtained through the measurement by the measurement optical system 10 and the post-operative corneal data inputted by the surgeon. The ablation data determined thereby is displayed on the display unit 43 in superposed relation with the map 70 and the sectional image 71 and other data. Also, the ablation thickness (ablation depth) and the ablation range are displayed numerically. (See Fig. 7.) In addition, the predicted post-operative refractive power and corneal radius are also displayed (not illustrated). Further, it is possible to designate a desired point by moving a cursor 72 on the map 70 so as to display corneal thickness and ablation thickness corresponding to each designated point as display 73 on the display.

[0037] The surgeon checks the map 70, the sectional image 71, the post-operative refractive power and the other data displayed on the display 43 to make sure that there is no problem. Having confirmed that there is no problem, the surgeon goes on to corneal surgery to ablate the cornea with an excimer laser beam. The surgeon operates the foot switch 7 to transmit laser irradiating signals to the control unit 40. Based on the obtained ablation data, the control unit 40 controls the irradiating optical system 25 (the driving circuits 47, 48 and 49) to perform ablation of the cornea in the way described later. In the case that the apparatus is not provided with the auto tracking mechanism, the alignment of the apparatus with the patient's eye needs to be performed again before irradiating the laser.

[0038] The control unit 40 drives the laser head 26 via the driving circuit 49 to emit the excimer laser beam. The emitted excimer laser beam is reflected and deflected by the mirror 27 and the dichroic mirror 17 and then converged by the lens 18. Thereafter, the control

unit 40 drives the scanning mirrors 19 and 20 via the driving circuits 47 and 48 respectively so as to aim the excimer laser beam at any intended spot. Having reached the cornea E positioned at the focal point of the lens 18, the excimer laser beam is made scan by the scanning mirrors 19 and 20 in the two-dimensional directions within the determined irradiation (ablation) range. The scan with the excimer laser beam in the two-dimensional directions may be done in linearly directions similarly to the scanning with the infrared laser beam for the corneal shape measurement, or in concentrically directions (direction as if to draw concentric circles or a spiral).

[0039] Since the excimer laser is a pulsed laser, the depth that the laser is able to ablate is controlled by the number of the pulses (by the irradiation time). For this reason, the control unit 40 drives the laser head 26 via the driving circuit 49 to irradiate the excimer laser for the duration of the number of pulses (irradiation time) corresponding to the necessary ablation amount. The excimer laser being controlled in the aforementioned way is irradiated at each scanning spot within the irradiation (ablation) range so as to ablate the corneal tissue needs to be removed for the refractive error correction. As the result, the patient's eye will have the intended refractive power.

[0040] Here, since the information about the corneal thickness is obtained, advantage of the information may be taken to perform surgery more appropriately. For example, comparison may be made between the determined amount of the cornea to be ablated and the thickness of the cornea to figure out the predicted thickness of the post-operative cornea (the thickness of the residual cornea after the ablation). If it is figured that the post-operative cornea is to be thinner than a predetermined standard, the irradiation of the laser is cancelled. Instead, the display unit 43 displays a warning or a not illustrated sound generator produce beep tones for warning. In addition, the laser head 26 and other components are controlled so as to irradiate the laser beam only when the thickness of the post-operative cornea is equal to, or thicker than the predetermined standard. This allows to eliminate the possibility of ablation when it should not be done. Further, the processing unit 42 may be made to adjust the ablation data (the irradiation range of the excimer laser and the like) so that the post-operative cornea is ensured to be thicker than the predetermined standard. The standard for the thickness of the post-operative cornea is determined with the use of the input unit 41.

[0041] Further, in the case of removing an affected part of the cornea such as opacity or the like, the irradiation conditions such as the irradiation range and the ablation depth are inputted by operating the input unit 41. In this case, also, the comparison is made between the determined amount of the cornea to be ablated and the thickness of the cornea. The irradiation of the laser beam is controlled based on the result of the comparison. In addition, instead of inputting the ablation depth, the thickness of the post-operative cornea may be inputted after confirming the pre-operative corneal shape displayed on the display unit 43.

[0042] As described above, if the optical axis of the measurement optical system 10 and that of the irradiation optical system 25 are made coaxial, a solution is presented to the conventional problem that the positional relationship between the patient's eye and the corneal shape measurement (topography) apparatus differs from the positional relationship between the patient's eye and the corneal surgery apparatus. In addition, the difference in the state of the patient's eye due to the difference in the position of the patient. The optical axis of the measurement optical system 10 and that of the irradiating optical system 25 do not necessarily have to be coaxial as long as the two optical axes have the known predetermined positional relationship therebetween. Yet, it is easier to control irradiation spot and the like if the two optical axes coincide with each other. In this embodiment, as for the irradiation method, the laser beam having a small circular section is scanned by the galvano-mirror. Alternatively, it is possible to use a laser beam having a rectangle irradiating section and scan the laser beam in one direction by a mirror, or instead its scanning direction may be rotated by an image rotator or the like.

[0043] In addition, a solution is provided also to another problem associated with a conventional apparatus which combines a placido ring projecting unit and a TV camera provided in a topography apparatus for photographing its corneal reflex and a laser irradiating optical system and an observation optical system provided in a corneal surgery apparatus. Making the two optical axes coaxial solves this problem of complication and enlargement of the apparatus.

[0044] Still further, since the corneal thickness is obtained through measuring the three-dimensional shapes of the anterior and the posterior cornea, determination may be made as to whether to proceed with the ablation or to warn the surgeon when the thickness of the post-operative cornea is expected to be thinner than that of the standard post-operative cornea. This eliminates the possibility of ablation when it should not be done.

[0045] Still further, the auto-alignment and the auto-tracking by the eyeball position detecting optical system in this embodiment may possibly be omitted. Also, the display of the corneal shape data may be modified to display more variety of data. Still further, in the corneal shape measurement optical system 10, the projecting optical system that projects the infrared laser beam being the measurement light onto the cornea E and the optical system that directs the reflected right from the cornea E to the photo-detector 23 are partially shared with each other. However, the two optical systems may be replaced with two totally separated optical systems. Yet, even in this case, the pinhole 13 and the pinhole 22

have to be arranged conjugate with each other relative to the cornea E.

Claims

1. A corneal surgery apparatus which ablates corneal tissue with a laser beam, the apparatus comprising:

   an irradiation unit including a light directing optical system for directing the laser beam to an intended range on a cornea of a patient's eye, wherein the laser beam has a wavelength in a far ultra-violet region and intensity capable of causing ablation; and
   a corneal shape measurement unit, provided inside the apparatus, for measuring a three-dimensional shape of the cornea, the corneal shape measurement unit including:

   a measurement light projecting optical system for projecting measurement light onto the cornea and its convergent point is shifted by moving a focusing lens along an optical axis;
   a measurement light receiving optical system including a photo-detector for receiving reflected light from the cornea and its convergent point is shifted by moving a focusing lens along an optical axis;
   a scanning unit for shifting a projection spot of the measurement light on the cornea in XY directions; and
   an arithmetic unit for performing arithmetic to obtain the three-dimensional shape of the cornea from a position of the projection spot, a result detected by the photo-detector and a position to which the focusing lens is moved.

2. The corneal surgery apparatus according to claim 1, wherein the light directing optical system forms a small spot with the laser beam at an irradiation position on the cornea and shifts the spot in XY directions.

3. The corneal surgery apparatus according to claim 2, wherein the light directing optical system comprises a focusing lens by which the small spot is formed with the laser beam on the cornea and the spot is sifted in XY directions, and further the light directing optical system moves the focusing lens along an optical axis in accordance with a position of the cornea in a Z direction.

4. The corneal surgery apparatus according to claim 1, wherein the light directing optical system comprises a scanning optical unit for forming a small spot with the laser beam at an irradiation position on the cornea and for shifting the spot in XY directions.

5. The corneal surgery apparatus according to claim 1, wherein the light directing optical system comprises a scanning optical unit for forming a small spot with the laser beam at an irradiation position on the cornea and for shifting the spot in XY directions, and

   an optical axis of the light directing optical system and an optical axis of the measurement light projecting optical system have a predetermined positional relationship therebetween and the scanning optical unit and the scanning unit are shared with each other.

6. The corneal surgery apparatus according to claim 1, wherein the measurement light projecting optical system comprises a first pinhole for limiting the measurement light, and the measurement light receiving optical system comprises a second pinhole at an optically conjugate position with the first pinhole for limiting incident light to the photo-detector.

7. The corneal surgery apparatus according to claim 1, wherein the convergent point of the measurement light projected by the measurement light projecting optical system is movable to an anterior cornea and to a posterior cornea, and

   the arithmetic unit obtains a position of the anterior cornea as well as a position of the posterior cornea.

8. The corneal surgery apparatus according to claim 7, wherein the arithmetic unit obtains data about a thickness of the cornea from the positions of the anterior cornea and the posterior cornea.

9. The corneal surgery apparatus according to claim 8, further comprising:

   input means for inputting at least one of a corrected refractive power to be acquired and post-operative corneal shape information;
   arithmetic means for performing arithmetic to obtain corneal ablation data from the inputted data and the three-dimensional shape of the cornea obtained by the arithmetic unit;
   judgment means for judging whether or not a thickness of the post-operative cornea meets a predetermined standard based on the ablation data and the data about the thickness of the cornea; and
   informing means for informing a judgement result made by the judgement means.

10. The corneal surgery apparatus according to claim 8, further comprising:

input means for inputting at least one of a corrected refractive power to be acquired and post-operative corneal shape information; and
arithmetic means for performing arithmetic to obtain corneal ablation data from the inputted data, the three-dimensional shape of the cornea and the data about the thickness of the cornea obtained by the arithmetic unit.

11. The corneal surgery apparatus according to claim 1, further comprising:

input means for inputting at least one of a corrected refractive power to be acquired and post-operative corneal shape information;
arithmetic means for performing arithmetic to obtain corneal ablation data from the inputted data and the three-dimensional shape of the cornea obtained by the arithmetic unit; and
irradiation control means for controlling operations of the irradiation unit in accordance with a result obtained by the arithmetic means.

12. The corneal surgery apparatus according to claim 1, further comprising:

input means for inputting at least one of a corrected refractive power to be acquired and post-operative corneal shape information;
arithmetic means for performing arithmetic to obtain corneal ablation data from the inputted data and the three-dimensional shape of the cornea obtained by the arithmetic unit; and
display means for graphically displaying the three-dimensional shape of the cornea obtained by the arithmetic unit and the ablation data obtained by the arithmetic means in superposed relation with each other.

13. The corneal surgery apparatus according to claim 1, further comprising a display unit for graphically displaying the three-dimensional shape of the cornea obtained by the arithmetic unit.

14. The corneal surgery apparatus according to claim 1, further comprising:

moving means for moving at least either the light directing optical system or the measurement light projecting optical system relative to the patient eye;
position detecting means for detecting an eyeball position of the patient's eye; and
movement control means for controlling the moving means in accordance with a result detected by the position detecting means.

15. The corneal surgery apparatus according to claim 14, wherein said position detecting means comprises:

illumination means for illuminating an anterior part of the patient's eye;
photoelectricity converting means for detecting light distribution of the anterior part being illuminated; and
pupil detecting means for detecting a position of a pupil of the patient eye by processing signals from the photoelectricity converting means.

FIG. 1

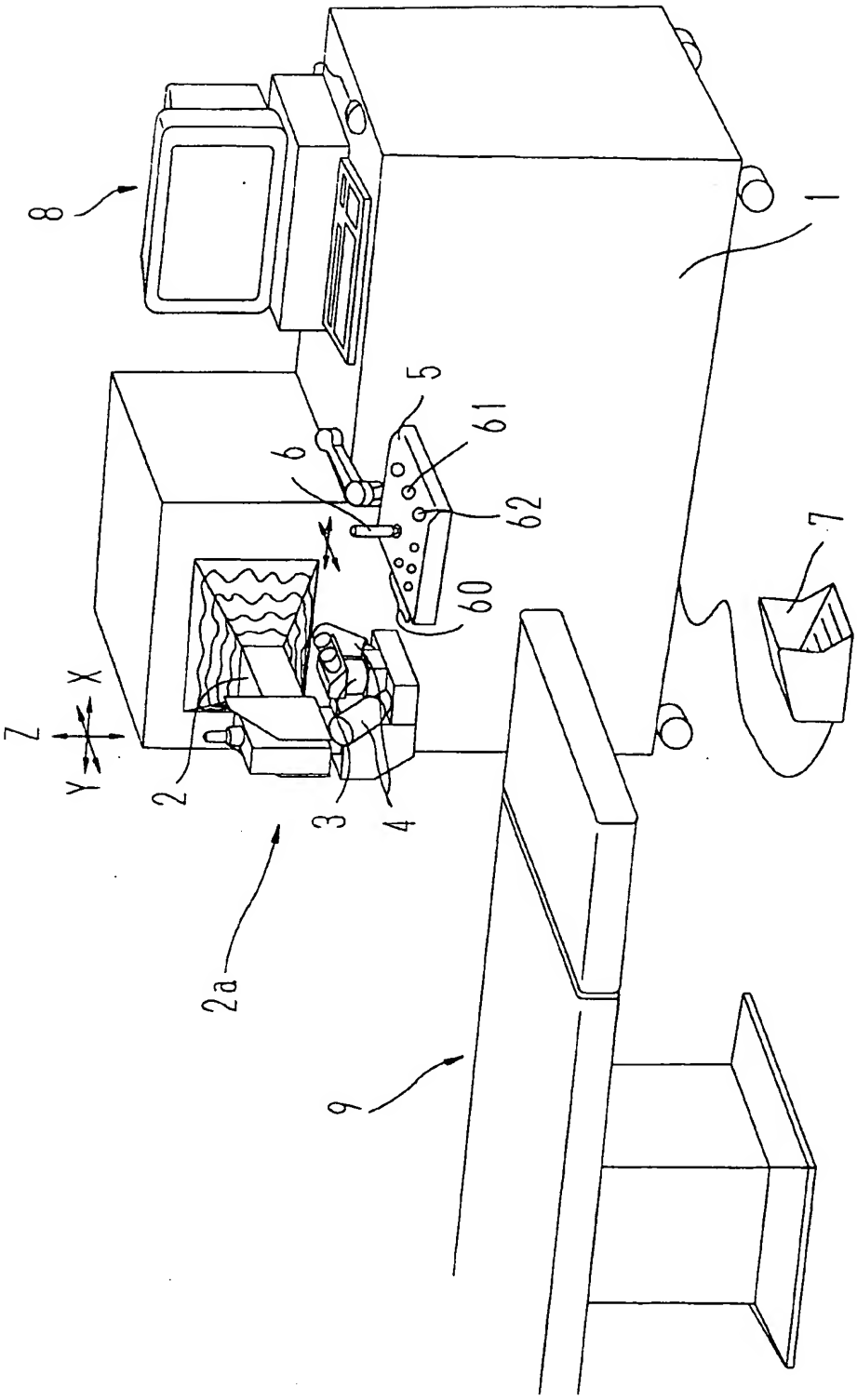


FIG. 2

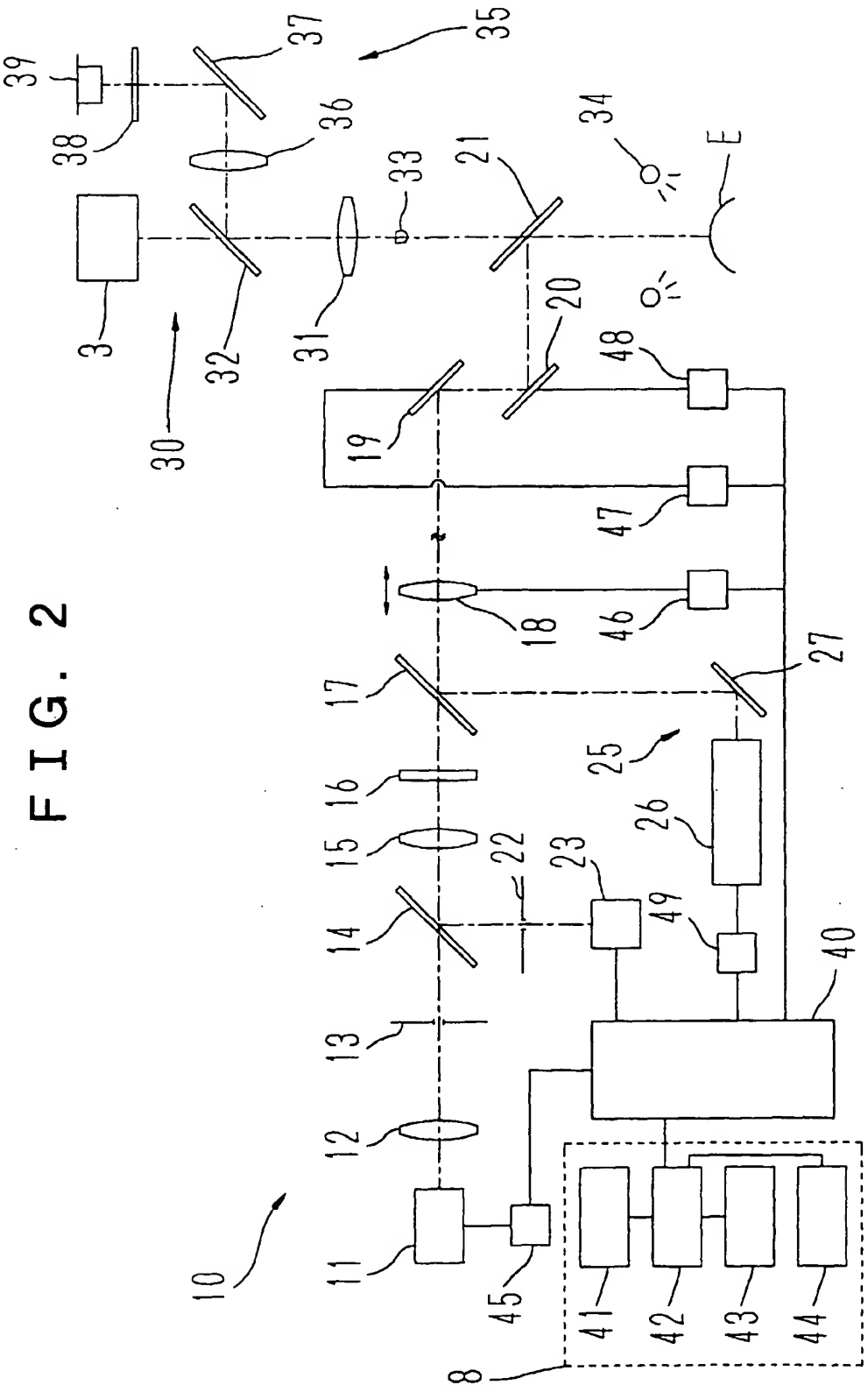

39
37
35
38
36
34
E
33
21
3
32
31
20
48
30
19
47
18
46
27
17
25
16
26
15
22
23
14
49
40
13
12
10
11
45
41
42
43
44
8

FIG. 3

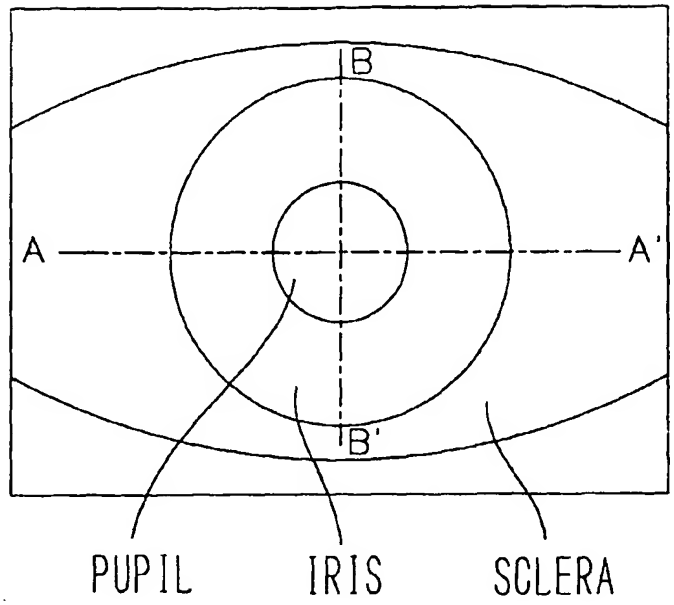


FIG. 4

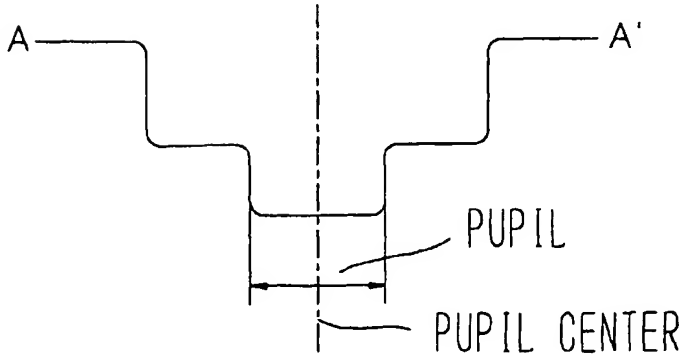


FIG. 5

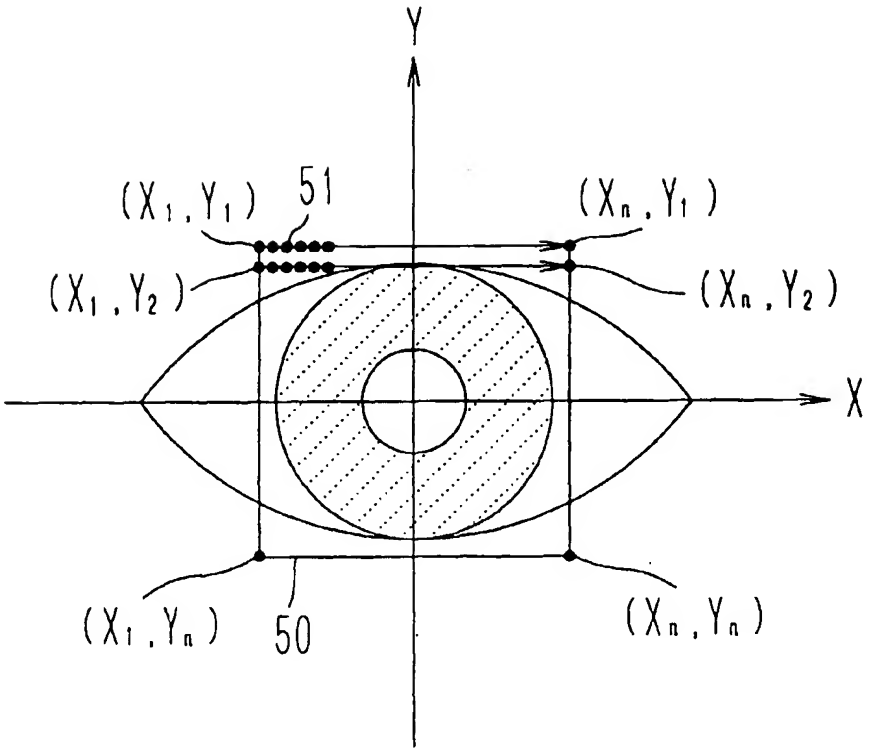


FIG. 6A

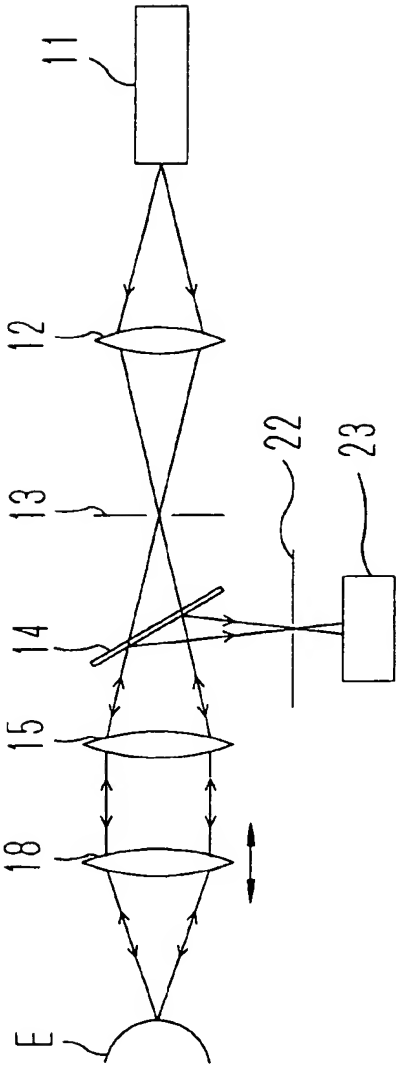


FIG. 6B

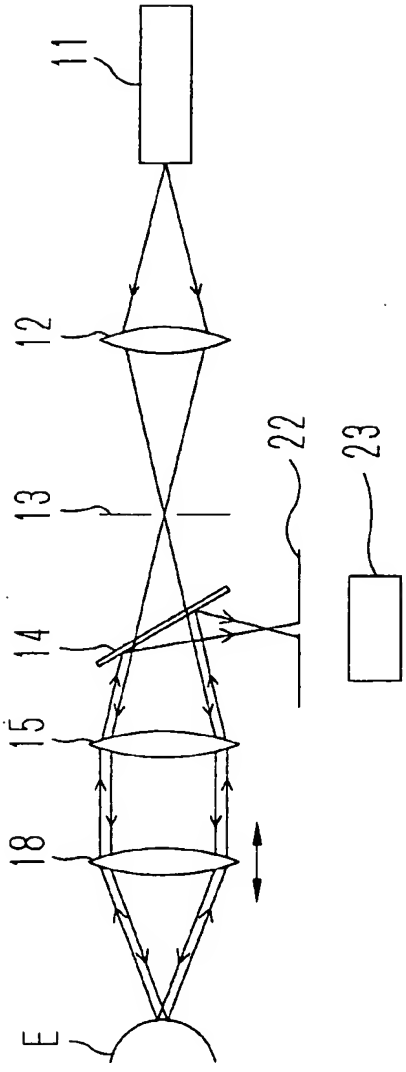
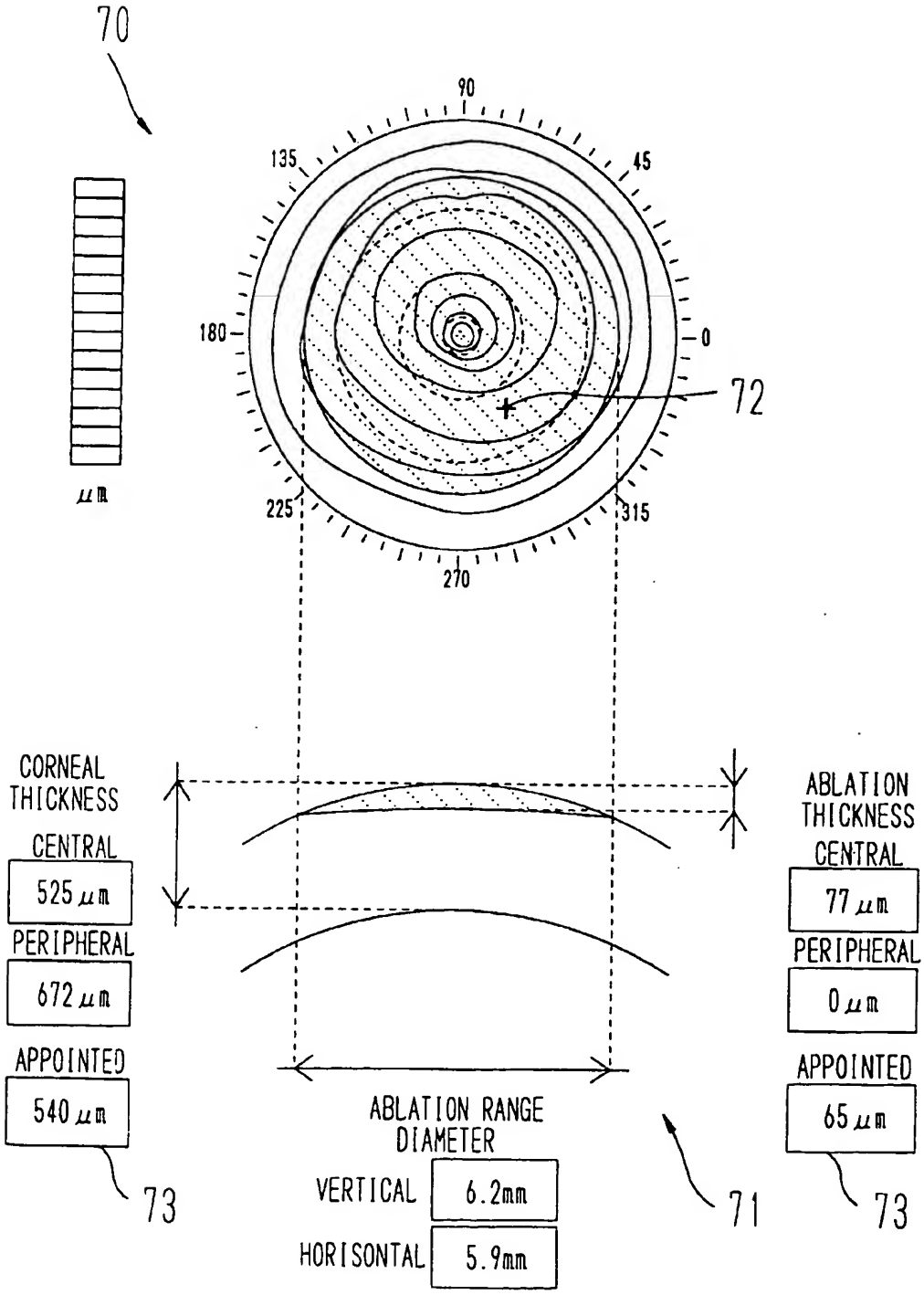


FIG. 7


70
90
135
45
180
0
225
315
270
μm
72
CORNEAL THICKNESS
CENTRAL
525 μm
PERIPHERAL
672 μm
APPOINTED
540 μm
73
ABLATION RANGE DIAMETER
VERTICAL
6.2mm
HORISONTAL
5.9mm
71
ABLATION THICKNESS
CENTRAL
77 μm
PERIPHERAL
0 μm
APPOINTED
65 μm
73

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 983 757 A3

(12) EUROPEAN PATENT APPLICATION

(88) Date of publication A3:
19.09.2001 Bulletin 2001/38

(43) Date of publication A2:
08.03.2000 Bulletin 2000/10

(21) Application number: **99117382.4**

(22) Date of filing: **03.09.1999**

(51) Int Cl.[7]: **A61F 9/01**, A61B 3/107

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **04.09.1998 JP 25152098**
03.06.1999 JP 15610299

(71) Applicant: **Nidek Co., Ltd.**
Gamagori-shi, Aichi 443-0035 (JP)

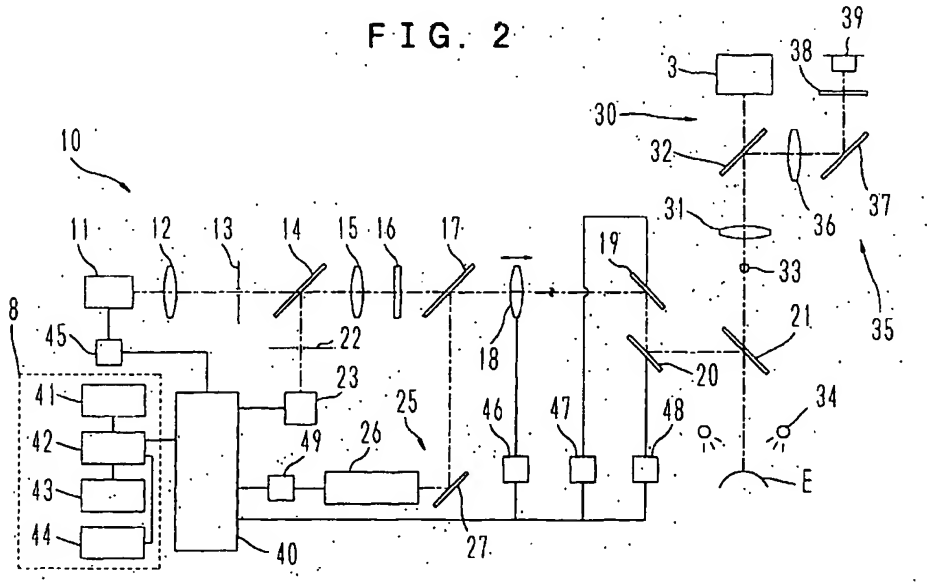
(72) Inventor: **Sumiya, Toshifumi**
Kota-cho, Nukata-gun, Aichi 444-0116 (JP)

(74) Representative:
Blumbach, Kramer & Partner GbR
Radeckestrasse 43
81245 München (DE)

(54) Corneal surgery apparatus

(57) In a corneal surgery apparatus (10), a corneal shape measurement unit for measuring a three-dimensional shape of a cornea (E) includes a measurement light projecting optical system (11) for projecting measurement light onto the cornea (E) and its convergent point is shifted by moving a focusing lens (18) along an optical axis, a measurement light receiving optical system including a photo-detector (23) for receiving reflected light from the cornea (E) and its convergent point is shifted by moving a focusing lens (18) along an optical axis, a scanning unit (19, 20) for shifting a projection spot of the measurement light on the cornea (E) in XY directions and an arithmetic unit (8) for performing arithmetic to obtain the three dimensional shape of the cornea (E) from a position of the projection spot, a result detected by the photo-detector (23) and a position to which the focusing lens is moved.

FIG. 2



EP 0 983 757 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 11 7382

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
Y	US 4 209 252 A (ARDITTY HERVE J ET AL) 24 June 1980 (1980-06-24) * column 8, line 60 - column 9, line 11; figure 4 *	1-4,6, 11-13	A61F9/01 A61B3/107
Y A	US 4 721 379 A (L ESPERANCE FRANCIS A) 26 January 1988 (1988-01-26) * column 3, line 45 - column 4, line 4; figure 1 * * column 5, line 4 - line 28 *	1-4,6, 11-13	
A	US 4 838 682 A (PORTNOY VLADIMIR) 13 June 1989 (1989-06-13) * column 4, line 7 - line 26; figures 1,6 *	1,7,8, 12,13	
A	US 4 665 913 A (L ESPERANCE JR FRANCIS A) 19 May 1987 (1987-05-19) * column 3, line 53 - line 62; figure 13 *	1-4	
A,D	EP 0 765 648 A (NIDEK KK) 2 April 1997 (1997-04-02) * abstract *	1,14,15	TECHNICAL FIELDS SEARCHED (Int.Cl.7) A61F A61B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	31 July 2001	Mayer, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 99 11 7382

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

31-07-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4209252 A	24-06-1980	NONE	
US 4721379 A	26-01-1988	US 4669466 A	02-06-1987
US 4838682 A	13-06-1989	CA 1296804 A	03-03-1992
		DE 3714896 A	12-11-1987
		FR 2598072 A	06-11-1987
		JP 62277937 A	02-12-1987
US 4665913 A	19-05-1987	CA 1271813 A	17-07-1990
		EP 0209992 A	28-01-1987
		ES 556431 D	16-03-1988
		ES 8801981 A	01-06-1988
		IL 79223 A	15-07-1992
		JP 1641615 C	18-02-1992
		JP 3000055 B	07-01-1991
		JP 62053650 A	09-03-1987
		KR 9307907 B	21-08-1993
		US 4770172 A	13-09-1988
		US 5807379 A	15-09-1998
		US 4718418 A	12-01-1988
		ZA 8604710 A	25-02-1987
		CA 1243732 A	25-10-1988
		DE 3481164 D	08-03-1990
		EP 0151869 A	21-08-1985
		JP 1685517 C	11-08-1992
		JP 3043904 B	04-07-1991
		JP 60119935 A	27-06-1985
		US 4773414 A	27-09-1988
		US 5507741 A	16-04-1996
		US 5312320 A	17-05-1994
		US 5188631 A	23-02-1993
		US 5219343 A	15-06-1993
		US 5207668 A	04-05-1993
		US 4732148 A	22-03-1988
		US 4729372 A	08-03-1988
		ZA 8407841 A	29-05-1985
EP 0765648 A	02-04-1997	JP 9149914 A	10-06-1997
		US 6159202 A	12-12-2000

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82